Global distribution of snow precipitation systems observed by GPM satellite

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Motivation

Two year observations from the GPM core satellite provide a unique opportunity to study the snow system at mid and high latitudes. This study address the following scientific questions:

- What is the general climatology of snow precipitation observed by GPM Ku-band of radar?
- Where are the snow systems with extreme sizes, intensities, and depths? And how much do they contribute to the global snow precipitation?
- What are the seasonal and diurnal variations of the properties of snow systems.
- What are the regional differences in snow system properties between Northern and Southern hemisphere and over land and ocean?

Data and Methods:

•Two years (April 2014 – March 2016) of Ku-band of precipitation radar (KuPR) version 4 data
•Snow Features (SFs) are defined by grouping the contiguous area of non-zero solid precipitation observed by the GPM Ku-band radar.

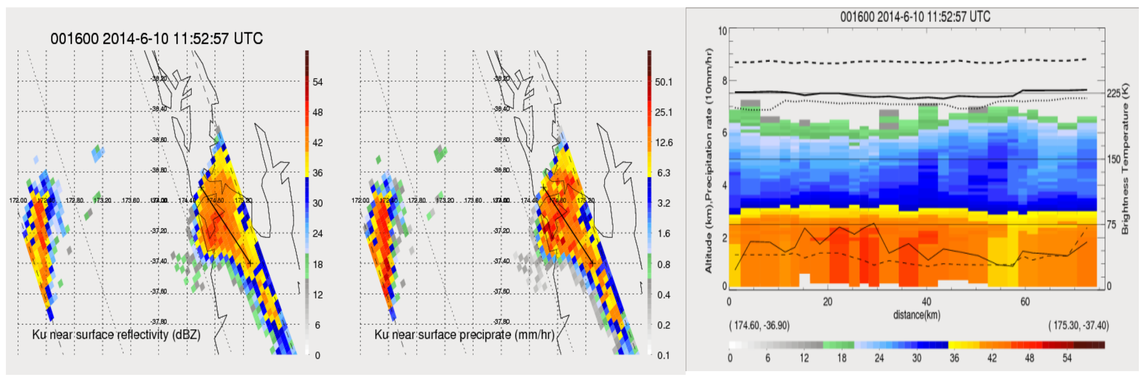


Figure 1: An example of snow precipitation retrieval over South Pacific Ocean near New Zealand.

•To avoid the complicated snow process over high mountains and large ground clutters, the samples over the elevation greater than 2 km are excluded. To remove some noise signal, small SFs with less than 20 pixels (~491 km^2) having echo top above 9 km are excluded from this study.
•SFs are analyzed over four regions, including Northern hemisphere (40^0 N-65^{0}N) and Southern hemisphere (40^0 S-65^{0}S) over land and ocean separately.
•To understand the weak snow that missed by Ku radar, climatology of snow rate is generated using 4-year (2007-2010) Cloudsat CPR level 2C snow profile data.

Snow detection and total accumulation by GPM KuPR and Cloudsat CPR

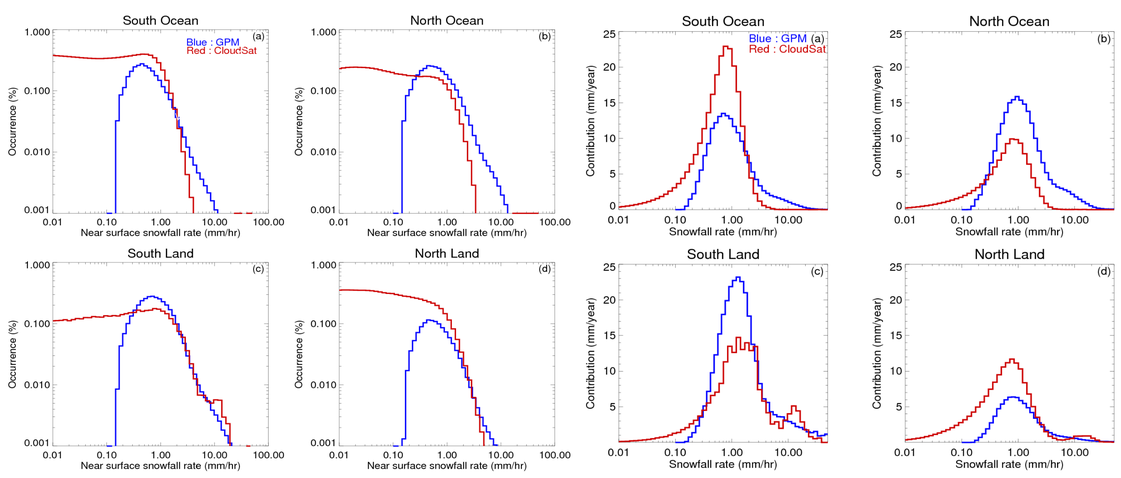


Figure 2: Occurrence of snow events at different snowfall rates over Northern and Southern hemispheric ocean and land from GPM Ku and CloudSat CPR.

Figure 3: Contribution of snow accumulation from different snowfall rates over Northern and Southern hemispheric ocean and land from GPM Ku and CloudSat CPR.

Table 1: Mean Occurrence of snow pixels and mean unconditional snowfall rate over Northern and Southern hemispheric ocean and land from GPM Ku and Cloudsat CPR

		Southern Ocean	Northern Ocean	Southern Land	Northern Land	Global (65^0 N/S)
Occurrence (%)	**GPM KU**	**2.88**	**3.04**	**3.35**	**1.20**	**1.25**
	Cloudsat CPR	**12.43**	**6.92**	**5.09**	**9.96**	**4.22**
Mean unconditional snowfall rate (mm/year)	**GPM KU**	**183**	**224**	**313**	**85**	
	Cloudsat CPR	**247**	**118**	**207**	**161**	

- GPM Ku radar can detect snowfall rate down to 0.1 mm hr^{-1} and it misses light snowfall rate.
- Cloudsat underestimates heavy snowfall (> 2 mm hr^{-1}) especially over ocean.
- GPM mean unconditional snowfall rate is higher than Cloudsat over Northern Ocean and Southern land

Seasonal and diurnal variations

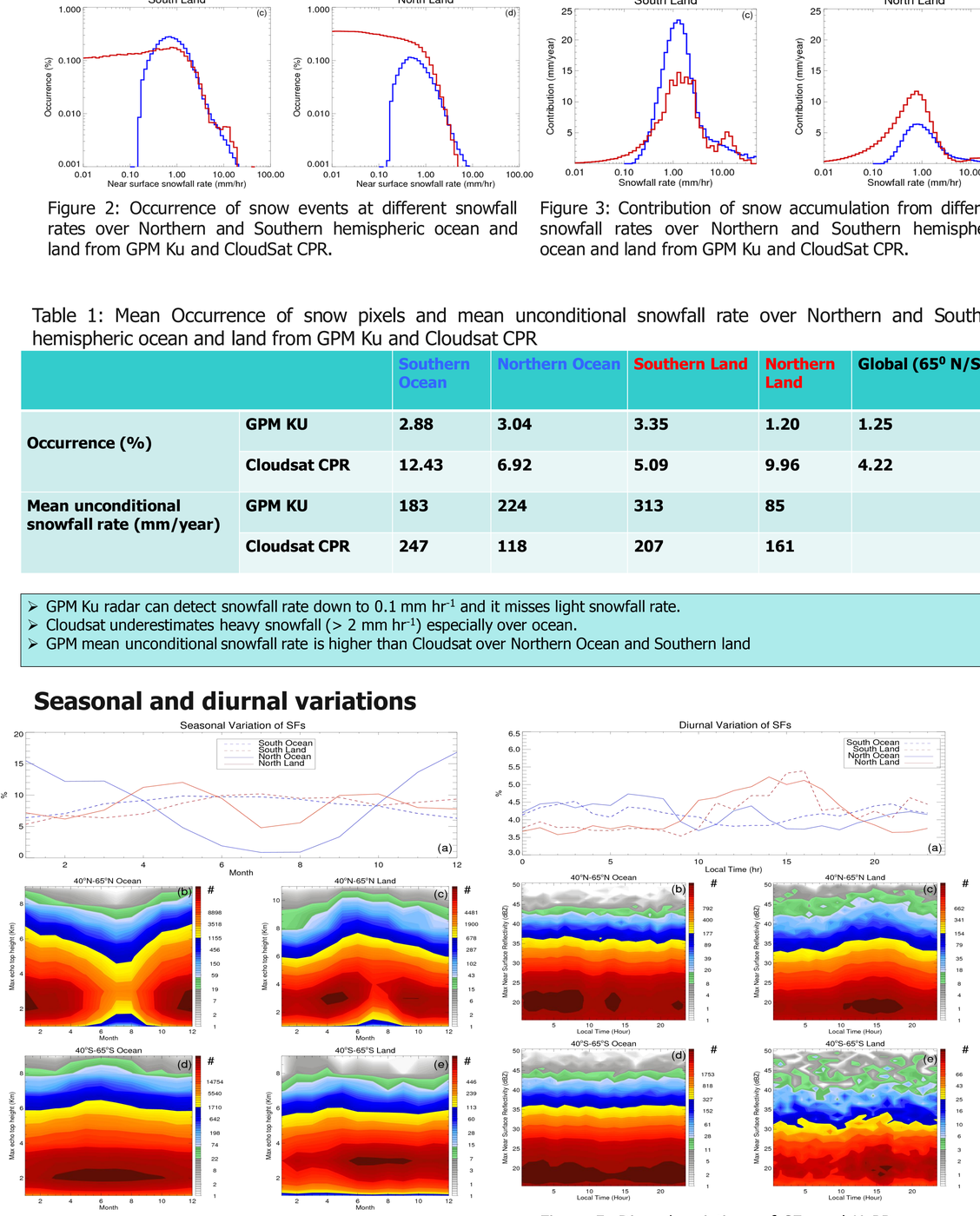


Figure 4: Seasonal variations of SFs and KuPR max echo top heights over Northern and Southern hemispheric ocean and land separately.

Figure 5: Diurnal variations of SFs and KuPR max near surface radar reflectivity over Northern and Southern hemispheric ocean and land separately.

- Northern hemispheric snow system shows strong seasonal variations in compare to southern hemisphere·
- SFs are shallower over ocean, but deeper over land in spring and fall than in winter, especially over northern hemisphere.
- Ocean SFs are shallower than over land.
- Strong diurnal variation has been observed over land than over ocean, and the peak is in the early afternoon.

Global snow climatology

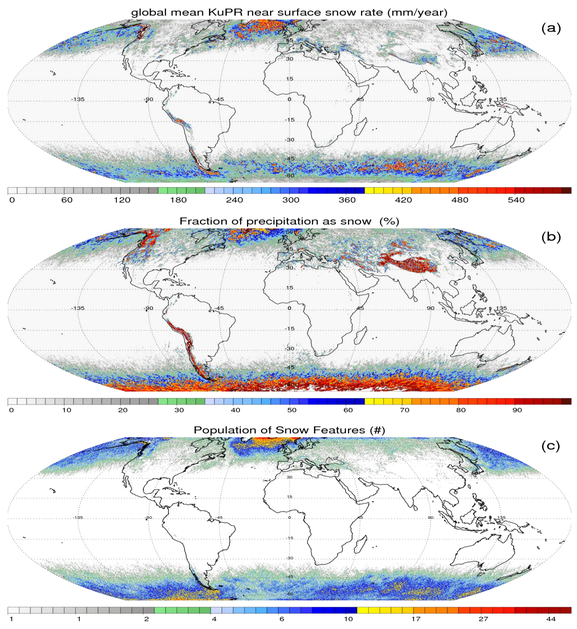


Figure 6. (a) unconditional KuPR near surface mean snowfall rate (mm/year), (b) percentage of precipitation as a snow, and (c) number of Ku PR snow features observation.

Sizes of snow features

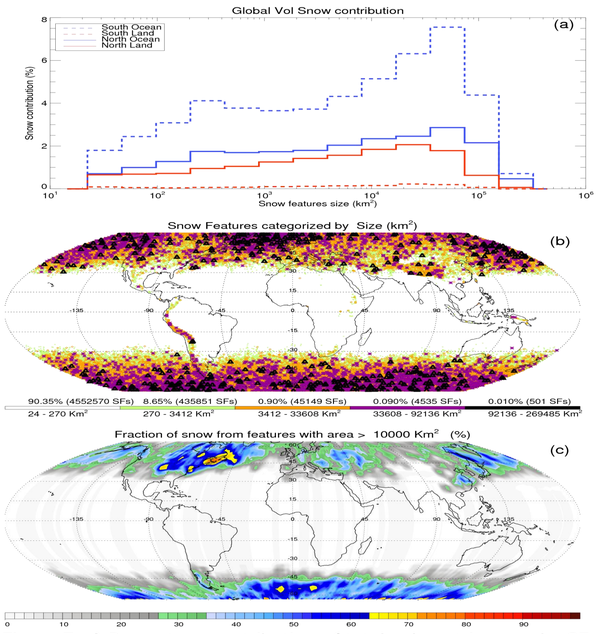
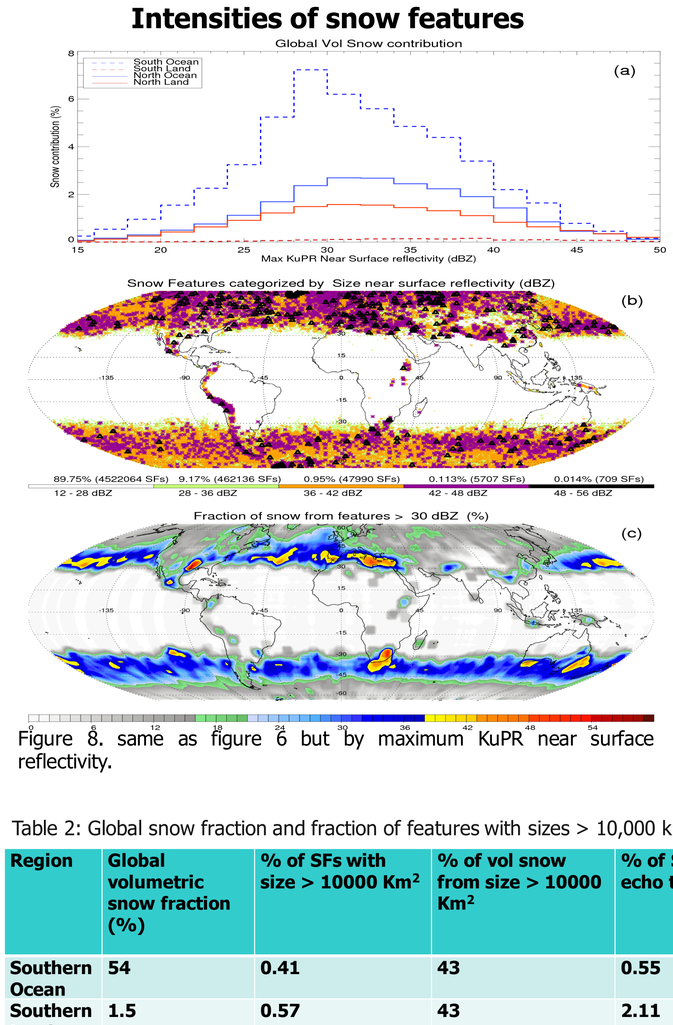


Figure 7. a) Percentage contribution of total volumetric snow by SFs of different Sizes, (b) Global locations of SFs categorized by size. Rarity of the events is represented by colored symbols: purple, ~ 0.09 %; and black, ~ top 0.01 %. (c) Geographical distribution of fraction of snow features from snow features size > 10000 Km^2.

Intensities of snow features



Depths of snow features

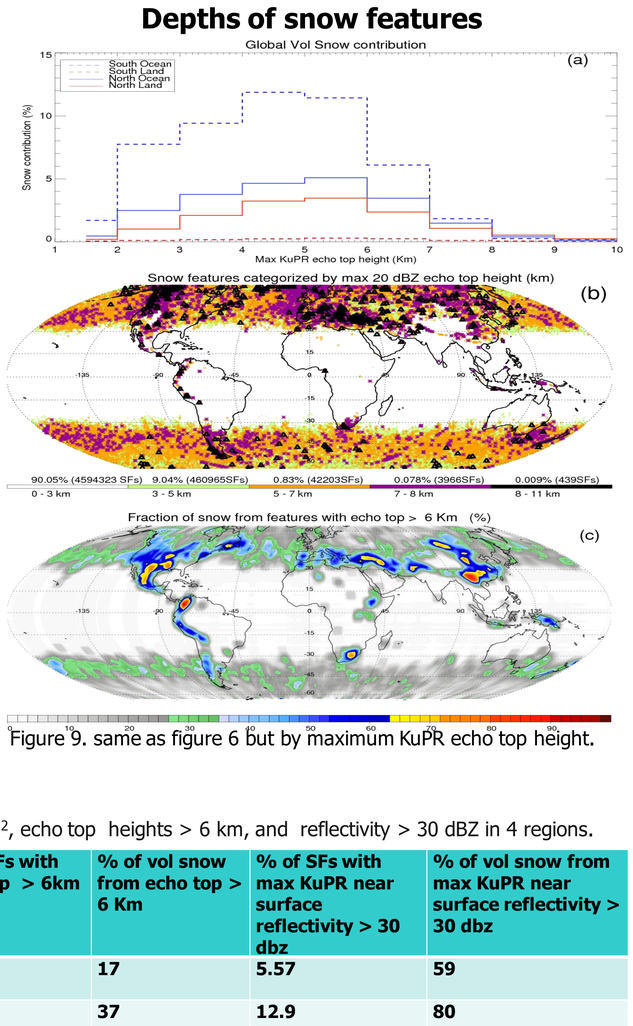


Figure 8. same as figure 6 but by maximum KuPR near surface reflectivity.

Figure 9. same as figure 6 but by maximum KuPR echo top height.

Table 2: Global snow fraction and fraction of features with sizes > 10,000 km^2, echo top heights > 6 km, and reflectivity > 30 dBZ in 4 regions.

Region	Global volumetric snow fraction (%)	% of SFs with size > 10000 Km^2	% of vol snow from size > 10000 Km^2	% of SFs with echo top > 6km	% of vol snow from echo top > 6 Km	% of SFs with max KuPR near surface reflectivity > 30 dbz	% of vol snow from max KuPR near surface reflectivity > 30 dbz
Southern Ocean	**54**	**0.41**	**43**	**0.55**	**17**	**5.57**	**59**
Southern Land	**1.5**	**0.57**	**43**	**2.11**	**37**	**12.9**	**80**
Northern Ocean	**24**	**0.39**	**42**	**1.07**	**26**	**7.5**	**68**
Northern land	**15**	**0.46**	**39**	**2.96**	**31**	**7.2**	**65**
Global		**0.40**	**40**	**1.26**	**22**	**6.6**	**62**

- The snow precipitation over southern hemisphere increases towards the pole where as over the Northern hemisphere, snow precipitation was geographically oriented which is consistent with CloudSat observation.
- More intense snow rates occur over the mid latitudes (35^0-45^0) than over the higher latitudes.
- A small percentage of the snow features are large (>10,000 Km^2), intense (>30dBZ) and deep (>6Km), they have a large contribution of total snow volume globally.

Properties of Snow Features

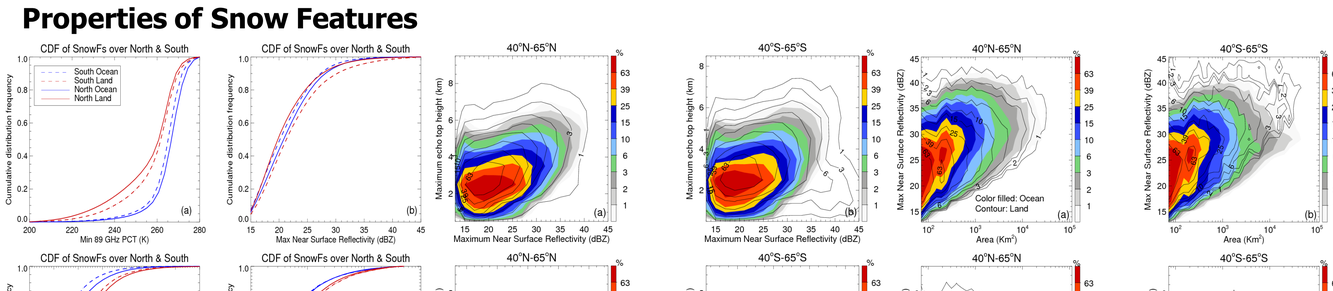


Figure 10: Cumulative distribution functions of (a) minimum 89 GHz PCT, (b) KuPR maximum near surface reflectivity, (c) maximum echo top height, and (d) sizes in SFs over 4 regions.

Figure 11: Cumulative two-dimensional histogram of SFs of max echo top height as a function of max KuPR near surface reflectivity (upper) and min 89 GHz PCT (lower). Colors filled are over ocean and contours are over land.

Figure 12: Cumulative two-dimensional histogram of SFs of max KuPR near surface reflectivity (upper) and max echo top height as a function of size (lower). Colors filled are over ocean and contours are over land.

- Most of the intense features are shallow with 2-5 km depths and these features are relatively smaller in sizes.
- Relatively colder, deeper and more intense features are observed over land than over ocean.

Summary:

- GPM misses significant amount of weak snow precipitation. It does capture a large proportion of total of snow precipitation.
- The differences between CloudSat and GPM in snow amounts varies significantly between land and ocean.
- Globally, very large sizes, more intense, and very deep snow system are found only 0.4%, 6.6%, and 1.26% but they contribute 40%, 62%, and 22% global volumetric snow respectively.
- Northern hemispheric snow system shows strong seasonal variations in compared to the southern hemisphere. Over Northern land, the snow features are larger and shallower over ocean and smaller and deeper in the fall and spring than in winter.
- Snow features with larger sizes are observed mainly over the ocean in both hemispheres. Over land, relatively cold, deep and intense features are observed.

Acknowledgements:
This research was supported by NASA Precipitation Measurement Mission grants NNX16AD76G under the direction of Dr. Ramesh Kakar. Thanks to Erich Stocker and the Precipitation Processing System (PPS) team at NASA Goddard Space Flight Center, Greenbelt, MD, for data processing assistance.